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Environmental Determinants and Origins of Malnutrition

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The characterization of protein-calorie malnutrition (PCM) more than 30 years ago led to its recognition as a scourge of underdeveloped societies (1). For more than two decades, however, PCM was considered a medical problem and was usually dealt with remedially, with little emphasis on correcting the socioeconomic factors that cause it. This was in part due to the emphasis placed on the study of the clinical and biochemical parameters of hospitalized malnourished children (2). There was little understanding of the magnitude of the mild and moderate forms of the disease and their social and economic implications.

Recently, a clearer concept of the significance of the mild and moderate forms of PCM has been obtained through interpretation of data on height, weight, food consumption, occurrence of infectious disease, and childhood mortality (3–5). Information on mild and moderate PCM has resulted from long-term prospective studies of rural populations in Africa and Latin America (6–8). It has become evident that malnutrition is an ecological problem requiring a multidisciplinary approach for its study, control and prevention. Research and intervention must be aimed at the environmental components that lead to malnutrition.

THE ENVIRONMENT OF THE MALNOURISHED CHILD

The geographic distribution of PCM shows a localization in tropical and subtropical regions; areas of famine are concentrated in the Indian Continent, equatorial Africa, and Northeastern Brazil where crowding, malnutrition, and lack of social development are more prevalent. For centuries, environmental forces in these areas have impeded socioeconomic growth and development.

Epidemiologically, the environment is classified into physical, biological, and social spheres; these aspects are all closely interrelated. The most important factors of the physical environment are the climate, the topography, and the composition of the soil (9). These influence food production and determine reservoirs and transmission of infectious agents harmful to plants, animals, and man. Tropical regions do not possess the most fertile soils; they lack marked seasons, and their relatively stable temperature and humidity favor propagation of plagues and pests of food crops and domestic animals, as well as the transmission of parasites and infectious agents that cause acute diarrheal disease. Furthermore, the high temperatures cause significant loss of body fluids and nutrients, resulting in a diminished work capacity (10,11). Conditions of heat stress (12) are common.

Cultural, societal, and economic factors are the most relevant components of the social environment. Cultural characteristics include literacy, level of personal hygiene (societies with low literacy level generally have poor standards of hygiene), and feeding habits, all of which are intimately related to the occurrence of PCM. Early malnutrition and diarrheal disease often result from supplementation of the weanling child with insufficient amounts of foods of low nutritional value, often contaminated with pathogenic bacteria. Cultural and behavioral factors are closely related to societal conditions like income, housing, water supply, and other community services. It is the social organization of most underdeveloped countries that makes progress difficult, if not impossible. Economic factors are linked to the others in the causation of malnutrition. Regions with prevalent malnutrition and famine are characterized by poor education, deficient housing, low social progress, low income, and low productivity (Fig. 1).

It is difficult to generalize about the social environment of different populations. However, the study of specific ecosystems offers an insight into ways that the socioeconomic situation affects health and nutrition. One such study

FIG. 1. Socioeconomic conditions in a typical Indian home. The hearth serves to cook tortillas (maize) and other foods. A mother prepares the *masa* (maize dough) on a metate placed on the floor, while her infant is at the breast. On the left side of the picture is a tapesco (rustic bed) that serves the entire family. At the right is a *tinaja* (large earthen jar) for storing water. Although the house is well kept, it still offers an excellent setting for the development of malnutrition and infection.

was conducted in a highland Indian village of Guatemala, Santa María Cauqué (8,13). As in most villages, tradition and custom are centuries old; in general, the rural way of life was stable for centuries before the modern appearance of improved transportation, communication, and alleviation of some serious epidemic diseases. Modernization was accompanied by alterations in the village which have profound implications for the future.

For example, a 10-year study of land availability revealed that, while the total area for cultivation remained largely fixed, the area per family decreased (14). A rise in price of fertilizers in the last 3 years and lack of improved agricultural technology have decreased food production. The population has grown by over 3%/year, a figure comparable to the rest of Guatemala and other Central American nations. The proportion of independent male farmers has dropped sharply, with a concomitant increase in the number of salaried laborers in plots of other villagers. Dependence of laborers on neighbors' plots is creating a system of servitude unlike any that existed in the past.

The lack of village opportunities to absorb the young workers and the fascination of urban life are stimulating migration of adult males and, to a lesser extent, of whole families; until recently, this emigration to the cities was small. Inflation probably plays an important role. Food prices have increased 100 to 150%, whereas salaries have increased by only 50%. Villagers must spend virtually all of their income on food.

Although the biological environment bears directly on the biomedical sciences, it also depends on the social and physical environment. Components of the biological environment include the flora and fauna of the region that provide food and the microbiota of man, animals, and plants that influence health. Infectious agents contribute to malnutrition and mortality. We found that serum immunoglobulin M (IgM) was elevated in 15% of the Guatemalan lowland neonates shortly after birth, confirming previous observations in Santa María Cauqué (15). Although the origin of the IgM has not been established, antenatal antigenic stimulation of the fetus by maternal infection seems likely. The high frequency of congenital and perinatal infection in American children of low social class (16) and in Santa María Cauqué (13) supports this idea.

Whatever the origin of the high IgM values, there can be no doubt that high rates of infection among rural women favor neonatal infection during and shortly after birth (13). Infection is a condition that persists throughout life, affected only by the host's adaptation to parasitism or by development of specific immunity and other forms of resistance. At first, frequency and duration of viral infections varied among children, but eventually all were similarly infected and shed viruses almost continuously (17). A similar pattern, although less intense, applied to infection with parasites, pathogenic bacteria, and other entities of the upper respiratory tract and skin. The derivations were based on an excess frequency of clinical manifestations (14,18) and a marked stimulus of the B-cell system (19,20).

THE GENESIS OF MALNUTRITION

Kwashiorkor is less frequently seen in Central America than previously. Urbanization, occupation of women in out-of-the-house jobs, and shortening of the breastfeeding period account for relatively more cases of marasmus than kwashiorkor and for the appearance of cases during the first few months of life.

Malnutrition begins during gestation; women living in rural areas and slums are often stunted, do not always supplement their deficient diets during pregnancy, and are continuously exposed to unsanitary conditions. The result is recurrent subclinical infection, infectious disease, and chronic maternal malnutrition (21). In Santa María Cauqué, the average height of child-bearing women is 143 cm (4 feet, 8 inches). About 7% of births are premature (less than 37 weeks gestation) and an additional 32% of the births have evidence of intrauterine growth retardation (less than 2,501 g with adequate gestational age) (Fig. 2) (14,22). Postmature infants were not observed during 9 years of the study.

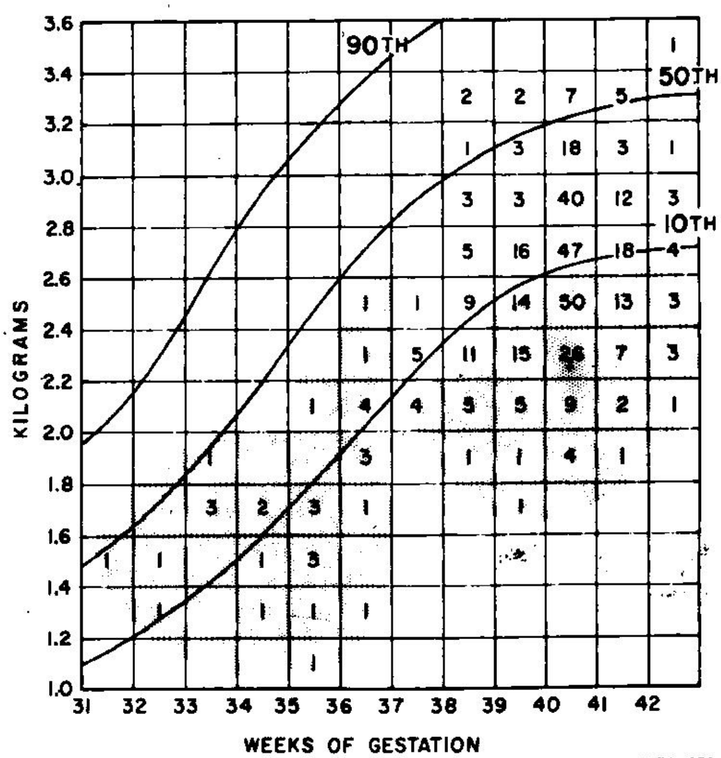

FIG. 2. Distribution of neonates by fetal maturity (Denver grid), all live born infants, Santa María Cauqué, 1964–1972 (14,22).

TABLE 1. *Infectious diseases during pregnancy, 365 women, Santa María Cauqué, 1964–1971*

Number of episodes per pregnancy	Number of pregnant women	Attack rate/ 100 women	Cumulative attack rate/ 100 women
0	106	29.0	
1	114	31.2	70.9
2	80	21.9	39.7
3	58	15.9	17.8
4	6	1.6	1.9
5	1	0.3	

Three maternal factors seem more important than others in the complex causation of prematurity and fetal growth retardation: height, diet, and infection. A strong positive correlation was observed between height of the mother and fetal growth (22); epidemiological evidence in humans (23) and in experimental animals (24) supports this observation. Diet during gestation is clearly important, although statistical manipulation frequently fails to show a strong association between pregnancy diet, and fetal growth. Maternal infection is a common occurrence, judging from the rates of intestinal parasitism, pathogenic enterobacteria, and infectious disease in general (Table 1) (22,25).

The high frequency of low-birth-weight infants in underdeveloped societies explains neonatal mortality figures, even in areas where tetanus neonatorum is not a problem. In the Guatemalan Indian village, neonatal mortality was 37 per 1,000 live births in 1964–1972, more than twice that of the United States in 1962. However, mortality is not particularly different when analyzed as a function of birth weight (Table 2) (26). This must be determined by events taking place before birth. Neonatal mortality can be significantly modified by improving fetal growth. In populations like the Indian village, an increase in women's height appears necessary for improved fetal growth, and this would take at least one generation.

TABLE 2. *Infant deaths per 1,000 live births, by birth weight. Infants from a Guatemalan Indian village and from the United States*[a]

Birth weight (g)	Neonatal			Postneonatal infant		
	S.M.C.	U.S.	r^b	S.M.C.	U.S.	r^b
1,501–2,000	273	210	1.3	303	26	11.7
2,001–2,500	34	45	0.8	34	13	2.6
2,501–3,000	10	10	1.0	43	7	6.1
3,001–3,500	0	5		23	5	4.6

[a] For Santa Maria Cauqué, 1964–1972; for the United States, data of H. C. Chase (1962).
[b] r, Ratio S.M.C./U.S.
(Adapted from Mata, ref. 26.)

Prematurity and fetal growth retardation are negatively correlated with postnatal physical growth (27). Cohorts of infants defined by birth weight, gestational age, or a combination of the two (fetal maturity) tend to remain in their growth tracks for weight, height, and head circumference (Fig. 3). This suggests that environmental forces exert an action of similar intensity on cohorts of children with different experiences of fetal growth and development. Conceivably, environmental manipulations could affect postnatal deficiencies in growth determined during gestation.

The main factors that interfere with a child's growth potential are infection and a deficient diet. In most societies, breastfeeding is customarily prolonged for 1 to 2 years, or even longer. At 6 months of age, maternal milk no longer meets the demands of the child; if the mother is malnourished, this occurs as early as 2 months of age. The supplementary foods that must be given are of

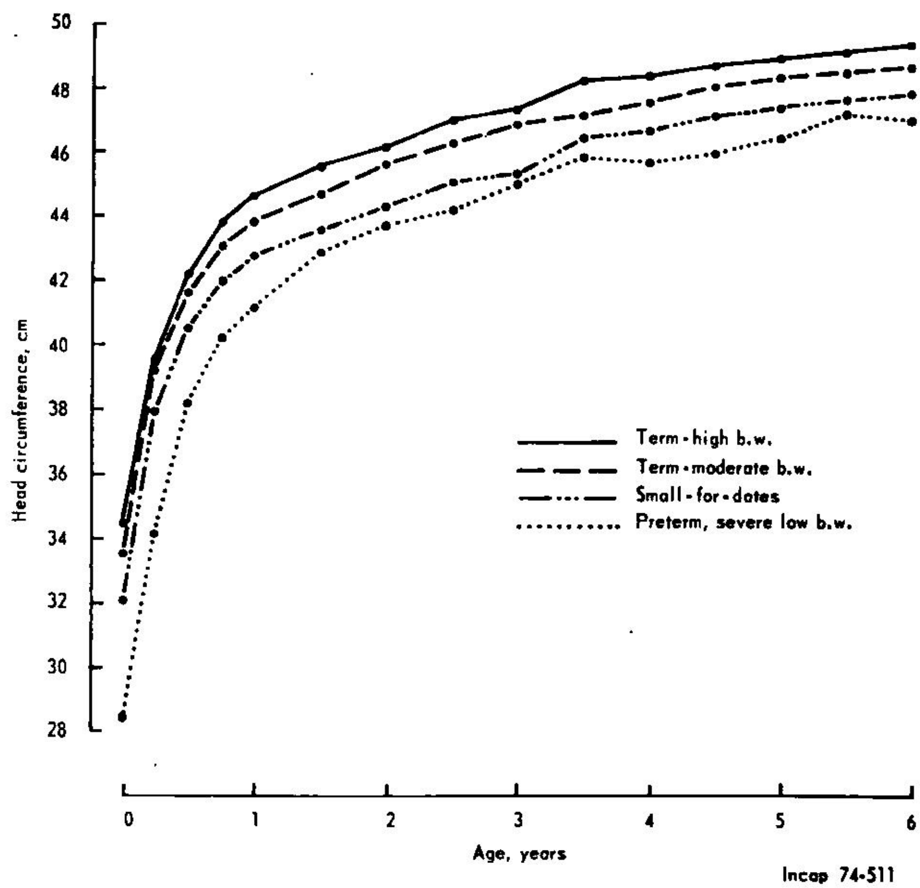

FIG. 3. Mean values, head circumferences from birth to 6 years, cohorts of children defined by fetal maturity, Santa María Cauqué, 1964–1972. High birth weight >3,001 g; moderate birth weight 2,501–<3,000 g; severe low birth weight 2,001 g.

low biological value, and are often contaminated with harmful infectious agents. This occurs at an age at which passive immunity is fading away and there is greater opportunity for infection. Thus the weaning period, which occurs during the second year of life in more traditional societies or during the first year in populations on the way to industrialization, results in recurrent infectious disease, deterioration of the nutritional state, and lowered resistance to infection (13,17,18,28,29).

The history of malnutrition and infection in a typical village child is presented in Fig. 4. Infections were common from birth onward, but until weaning the child was relatively protected by the wholesomeness of breast milk and by passive immunity. The critical weaning period extends from 3 to 6 months to about the end of the second year of life; the malnutrition-infection

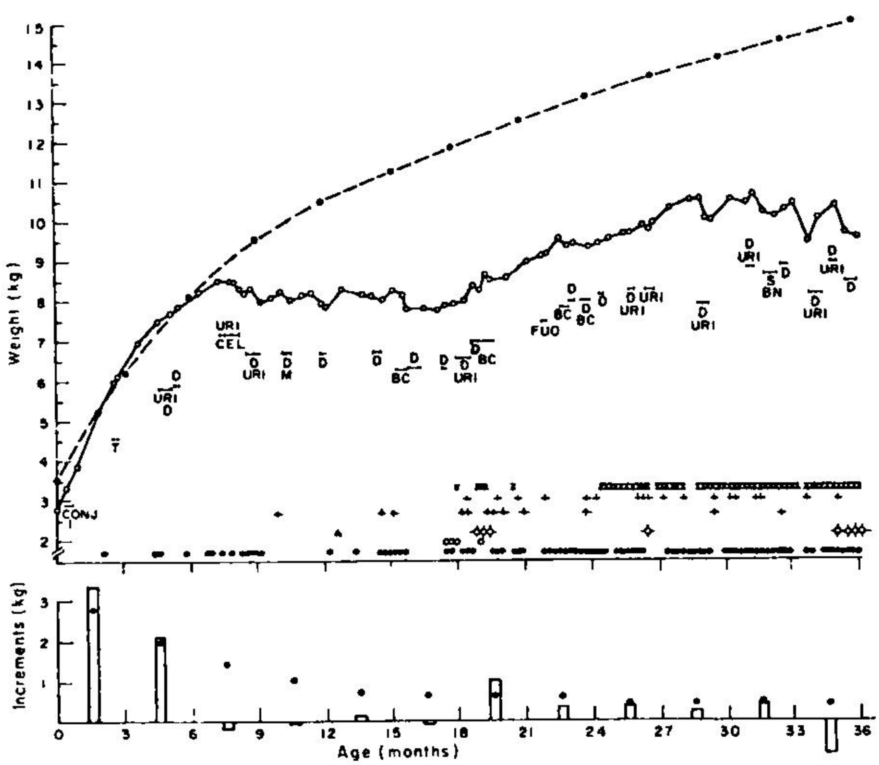

FIG. 4. Weight, infections, and infectious diseases in a male child. *Top:* The solid line represents the weight of the child; the broken line is the median of the Iowa standard. The length of each horizontal line indicates duration of infectious disease. BC, Bronchitis; BN, bronchopneumonia; CEL, cellulitis; CONJ, conjunctivitis; D, diarrhea; FUO, fever of unknown origin; I, impetigo; M, measles; S, stomatitis; T, oral thrush; URI, upper respiratory infections. Each mark shows a week positive for the particular infectious agent. (X), Ascaris; (+), Entamoeba histolytica; (+), Giardia lamblia; (◊), Shigella; (▲), enteropathogenic Escherichia coli; (O) adenovirus; (●) enterovirus. *Bottom:* Observed weight increments (vertical bars) and expected median increments (dots) of the Iowa standard. (From Mata et al., ref 18; Scrimshaw, ref. 33.)

interaction continues into the third and even the fourth year. Its immediate consequences are growth retardation and high mortality rates.

Mortality in the postneonatal infant and preschool child (Table 3) is higher in those who were small for gestational age than those who were preterm (26). Deficits in growth can be categorized as "wasting" (a deficit of weight for height), "stunting" (a deficit of height for age), or a combination of the two (30). Children who are both wasted and stunted are the more seriously malnourished and exhibit marked physiological alterations and a high mortality rate. Wasted children apparently show no significant alterations after recovery by proper feeding. Stunted children have been chronically malnourished; after recovery, they show no abnormalities except for a diminished output of insulin in response to a glucose load and an occasionally reported altered immune response. Although severely malnourished children show impaired psychomotor and intellectual function, no definitive relation can be established in humans between mild and moderate forms of PCM and impaired mental development (31).

TABLE 3. *Childhood mortality by fetal maturity, infants followed prospectively into the fourth year of life, Santa María Cauqué, 1964–1972*

Class	1st year	2nd year	3rd year	4th year
Preterm	16[a] (516)[b]	0	0	0
	$n = 31$	$n = 15$	$n = 13$	$n = 8$
Term, small for	12 (84)	8 (76)	3 (39)	3 (50)
gestational age	$n = 143$	$n = 105$	$n = 78$	$n = 60$
Term	12 (50)	9 (44)	5 (33)	1 (8)
	$n = 242$	$n = 204$	$n = 153$	$n = 122$
Total	40 (96)	17 (52)	8 (33)	4 (21)
	$n = 416$	$n = 324$	$n = 244$	$n = 190$

[a] Number of deaths.
[b] Deaths per 1,000 living children beginning period.
n, Population beginning period. Attrition is due to varying age of cohorts.
(Adapted from Mata, ref. 26.)

Physical growth retardation is significant because of its associated morbidity and mortality. The high frequency of infectious disease in malnourished children results from the interaction of an altered immune system and increased exposure to infectious agents. The child with anorexia, vomiting, and diarrhea may be neglected by the mother and relatives. Traditions, beliefs, and taboos affect the diet and management of illness. Although primary malnutrition may go unnoticed by the family, the suffering induced by morbidity alters family and societal stability.

Weaning eventually leads to an adaptation to the environment, in part by development of immunity, especially to many community infectious agents, and by better utilization of village foods. The child can secure food for himself without depending entirely on his mother. At 4 years of age, adequate growth rates are common, although the child may already be moderately stunted, wasted, or both. Wasting disappears with age and many village adults become overweight; deficits in height are permanent.

OPTIONS FOR THE FUTURE

Several considerations appear obvious from the above description. One is that conditions in the Indian village and in similar societies can only favor repeated generations of small-for-date infants who will become malnourished and experience increased morbidity and mortality. Survivors will be stunted and will produce small-for-date infants.

Another consideration is the impact of science and technology on the future of rural populations. Even though village life in many areas is rather stable, an improvement in communication and in societal organization has resulted in provision of services, vaccines, drugs, and knowledge, which have reduced mortality figures while the birthrate has remained stable. This has resulted in an unchecked population expansion in Santa María Cauqué. Whereas it could be judged unscientific to make predictions for the village and the country, several possibilities must be considered. Without significant social improvements, the present demographic growth will be maintained and the quality of human life will become worse. Overcrowding, pestilence, and famine may reappear. In fact, the regional epidemic of Shiga dysentery in 1969–1971 (32), favored by poverty, poor sanitation, and crowding may have been an omen of difficult times ahead. The application of fragmentary knowledge or of independent interventions will maintain the status quo or will make it worse. Nutrition rehabilitation centers, vaccination programs, and similar types of actions often will fail if they are not adequately supported and maintained. Furthermore, when such programs are not accompanied by a general improvement in the quality of life, through better distribution of income, privileges, and community services, they can stimulate demographic growth without the occurrence of comparable socioeconomic growth and development. Alternatives could be political upheaval and territorial expansion, or attainment of a situation of no return under which social and economic development stagnates for prolonged periods of time.

The only solution appears to be in the form of general socioeconomic improvement, which must come from the underdeveloped societies themselves, with cooperation of the industrial world powers. The underdeveloped nations that are reaching, or have reached, the point of land saturation should commit themselves to whatever sacrifices are necessary to improve the status quo. The leading nations must recognize this situation and devote an appreciable part of their political, economic, and social potential to help to effect change.

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REFERENCES

1. Scrimshaw, N. S., and Béhar, M. (1959): World-wide occurrence of protein-calorie malnutrition. *Fed. Proc.*, 18:82–88.
2. Brock, J. F., and Autret, M. (1952): *Le Kwashiorkor en Afrique*. Organization Mondiale de la Santé: Serie de Monographies, No. 8, Geneve. Etudes de Nutrition de la FAO, No. 8. Rome.
3. Bengoa, J. M. (1969): Malnutrition and infectious diseases—The "surviving child." *Biotech. Bioeng.*, Symposium No. 1, edited by E. L. J. Gaden, pp. 253–276.
4. Puffer, R. R., and Serrano, C. V. (1973): *Patterns of Mortality in Childhood.* PAHO Sci. Pub. No. 262, XIX. Wash., D.C.
5. Goldsmith, G. A. (1974): Current status of malnutrition in the tropics. *Am. J. Trop. Med. Hyg.*, 23:756–766.
6. McGregor, I. A., Billewicz, W. Z., and Thomson, A. M. (1961): Growth and mortality in children in an African village. *Br. Med. J.*, 2:1661–1666.
7. Cravioto, J., de Licardie, E. R., and Birch, H. G. (1966): Nutrition, growth and neurointegrative development: An experimental and ecological study. *Pediatrics,* 38:319–372.
8. Mata, L. J., Urrutia, J. J., and García, B. (1967): Effect of infection and diet on child growth: Experience in a Guatemalan village. In: *Nutrition and Infection.* Ciba Foundation Study Group No. 31, edited by G. E. W. Wolstenholme and M. O'Connor, pp. 112–126. Little Brown, Boston.
9. Sanchez, P. A., and Buol, S. W. (1975): Soils of the tropics and the world food crisis. *Science,* 188:598–603.
10. Astrand, P. O., and Rodahl, K. (1970): *Textbook of Work Physiology,* p. 517, pp. 523–524. McGraw-Hill, New York.
11. Scrimshaw, N. S., Taylor, C. E., and Gordon, J. E. (1968): *Interactions of Nutrition and Infection.* WHO Monograph Ser. No. 57, p. 39.
12. Leithead, C. S. (1968): Occupational heat stress, and man's responses. *Bull. Org. Mond. Santé,* 38:649–657.
13. Mata, L. J., Urrutia, J. J., Cáceres, A., and Guzmán, M. A. (1972): The biological environment in a Guatemalan rural community. In: *Proc. West. Hemisphere Nutr. Congr. III,* edited by P. L. White and N. Selvey, pp. 257–264. Futura, New York.
14. Mata, L. J. (1976): *The Children of Santa María Cauqué. A Prospective Study of Health and Growth.* MIT-Cornell Press, Cambridge, Mass.
15. Lechtig, A., and Mata, L. J. (1971): Levels of IgG, IgA and IgM in cord blood of Latin American newborns from different ecosystems. *Rev. Latinoam. Microbiol.*, 13:173–179.
16. Alford, C. A., Foft, J. W., Blankenship, W. J., Cassady, G., and Benton, J. W. Jr. (1969): Subclinical central nervous system disease of neonates: A prospective study of infants born with increased levels of IgM. *J. Pediat.*, 75:1167–1178.
17. Mata, L. J., Urrutia, J. J., Albertazzi, C., Pellecer, O., and Arrellano, E. (1972): Influence of recurrent infections on nutrition and growth of children in Guatemala. *Am. J. Clin. Nutr.*, 25:1267–1275.
18. Mata, L. J., Urrutia, J. J., and Lechtig, A. (1971): Infection and nutrition of children of a low socioeconomic rural community. *Am. J. Clin. Nutr.*, 24:249–259.
19. McGregor, I. A., Rowe, D. S., Wilson, M. E., and Billewicz, W. A. (1970): Plasma immunoglobulin concentrations in an African (Gambian) community in relation to season, malaria and other infections and pregnancy. *Clin. Exp. Immunol.*, 7:51–74.
20. Cáceres, A., and Mata, L. J. (1974): Niveles de inmunoglobulinas en una población del altiplano guatemalteco. *Bol. San. Pan.*, 76:115–124.

21. Lechtig, A., Habicht, J-P., Guzmán, G., and Girón, E. M. (1972): Influencia de las características maternas sobre el crecimiento fetal en poblaciones rurales de Guatemala. *Arch. Latinoam. Nutr.*, 22:255–265.
22. Mata, L. J., Kronmal, R. A., Urrutia, J. J., and García, B. (1975): Antenatal events and postnatal growth and survival of children. Prospective observation in a rural Guatemalan village. *Proc. West. Hemisphere Nutr. Cong. IV*, edited by P. L. White and N. Selvey, pp. 107–116. Pub. Sciences Group, Inc.
23. Gruenwald, P., Funakawa, H., Mitani, S., Nishimura, T., and Takeuchi, S. (1967): Influence of environmental factors on foetal growth in man. *Lancet*, 1:1026–1028.
24. Stewart, R. J. C. (1972): Small-for-date offspring: An animal model. In: *Nutrition, the Nervous System, and Behavior.* PAHO Sci. Pub. No. 251, pp. 33–37.
25. Urrutia, J. J., Mata, L. J., Trent, F., Cruz, J. R., Villatoro, E., and Alexander, R. E. (1975): Infection and low birth weight in a developing country. A study in an Indian village of Guatemala. *Am. J. Dis. Child.*, 129:558–561.
26. Mata, L. J. (1975): Malnutrition-infection interactions in the tropics. *Am. J. Trop. Med. Hyg.*, 24:564–574.
27. Mata, L. J., Urrutia, J. J., Kronmal, R. A., and Joplin, C. (1975): Survival and physical growth in infancy and early childhood. Study of birth weight and gestational age in a Guatemalan Indian village. *Am. J. Dis. Child.*, 129:561–566.
28. Salomon, J. B., Mata, L. J., and Gordon, J. E. (1968): Malnutrition and the common communicable diseases of childhood in rural Guatemala. *Am. J. Pub. Health*, 58:505–516.
29. Faulk, W. P., DeMaeyer, E. M., and Davies, A. J. S. (1974): Some effects of malnutrition on the immune response in man. *Am. J. Clin. Nutr.*, 27:638–646.
30. Waterlow, J. C., and Rutishauser, H. E. (1974): Malnutrition in man. In: *Symposium on Early Malnutrition and Mental Development.* Swedish Nutrition Foundation Symposia XII, pp. 13–26.
31. Organizacion Mundial de la Salud (1974): Malnutrición y desarrollo mental. *Crónica OMS*, 28:103–110.
32. Mata, L. J., and Castro, F. (1974): Epidemiology, diagnosis, and impact of Shiga dysentery in Central America. In: *Industry and Tropical Health VIII*, Harvard School of Public Health, pp. 30–37.
33. Scrimshaw, N. S. (1975): Interactions of malnutrition and infection: Advances in understanding. In: *Protein-Calorie Malnutrition,* edited by R. E. Olson, p. 355. Academic Press, New York.